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**Intermountain
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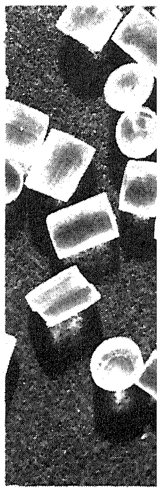
Ogden, UT 84401**

General Technical
Report INT-137

December 1982

Aerial Application of Douglas-fir Beetle Antiaggregative Pheromone: Equipment and Evaluation

Malcolm M. Furniss, George P. Markin, and Victor J. Hager



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The manuscript was strengthened by the critical reviews of Dr. R. Ladd Livingston, Idaho Department of Lands; and William M. Ciesla and Mark D. McGregor, USDA Forest Service.

RESEARCH SUMMARY

The Douglas-fir beetle antiaggregative pheromone, MCH (3-methyl-2-cyclohexen-1-one), has been shown to prevent to a high degree infestation of susceptible felled trees. This publication describes technology for application and evaluation of a granular controlled-release formulation containing 2 percent MCH. Included is a chronological discussion of developmental steps leading to modification and testing of a 40-ft^3 (1.13-m^3) bucket-type Simplex model 6400 aerial applicator for use in applying variable-size granules by helicopter at a recommended rate of approximately 4 lb/acre (4.48 kg/ha). Rate of application was measured on plots by conical traps. Methods of bioassaying MCH treatment, involving counts of attack sites (frass piles), bark samples, and measuring tree mortality, are discussed.

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INTRODUCTION

The Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae* Hopkins, is an important bark beetle in Douglas-fir forests of western North America (Furniss and Orr 1978). It often kills mature, dense groups of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, after its population increases in windfelled or otherwise susceptible trees. Preventive measures include maintaining stands below 80 percent of normal stocking and salvaging damaged trees. When windstorms fall trees in inaccessible locations, however, an alternative action is needed. For example, the antiaggregative pheromone, MCH, might be applied to deny beetles susceptible windfelled trees in which to breed, thereby maintaining the population status quo (Furniss and others 1981). Thus, the population is held in check by diverting beetles from susceptible windfelled trees to a more hostile environment, including live trees that have greater resistance than do felled trees. How to do so is the subject of this publication. Included is a chronological account of steps taken to modify and test the applicator, and suggestions for evaluating treatment.

Discovery of the attractant pheromone complex of *Ips paraconfusus* Lanier (Wood and others 1967) opened up a field of study that has resulted in identifying pheromones of many scolytids (Borden 1974, 1977). Among these are the DFB antiaggregative pheromone, 3-methyl-2-cyclohexen-1-one (MCH) (Kinzer and others 1971). The natural function of MCH is to reduce intraspecific competition by terminating attraction after a generally sufficient attack density has been achieved to overcome a tree's defenses (Rudinsky and Ryker 1976). Whether MCH masks the attractive pheromones frontalin (Pitman and Vité1970) and seudenol (Pitman and others 1974), which are synergized by α-pinene (Furniss and Schmitz 1971), or whether MCH repels beetles, is uncertain.

Evaporation of MCH from glass vials in the vicinity of recently felled Douglas-fir reduced subsequent DFB attack densities up to 96 percent compared to untreated trees (Furniss and others 1974). A granular controlled-release formulation (U.S. Patent #4,170,631) containing 2 percent MCH proved to be equally effective when broadcast by hand around felled trees (Furniss and others 1977). The rod-shaped granules (fig. 1) vary severalfold in mass, and the technology for aerially applying small amounts, e.g., 4 lb/acre (4.48 kg/ha) of such granules was not available. Therefore, we adapted a fertilizer applicator to this purpose by modifying its rate of output and electrical circuitry. Other information presented are: calibration data, swath width, flight specifications, and methods of evaluating application rate and effectiveness of treatment.

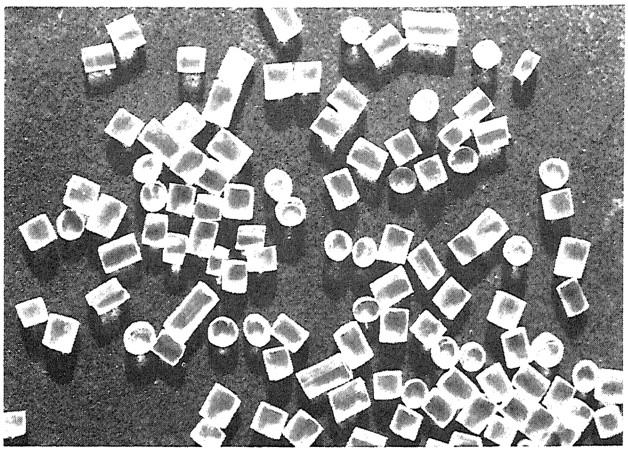


Figure 1.—MCH is evaporated slowly from rod-shaped inert granules.

APPLICATION TECHNOLOGY

Chronology of Testing and Problems Encountered

SIMPLEX MODEL 1600 SEEDER

In 1976 we began testing and developing technology needed to apply the granular controlled-release formulation of MCH at a rate of approximately 4 lb/acre (4.48 kg/ha) containing 2 percent actual MCH. Initially we tested a series 1600 Simplex[1] seeder on a Hiller 12E helicopter (fig. 2). A feeder mechanism was located beneath each hopper on either side of the helicopter. Each feeder consisted of a sliding gate to regulate the amount of granules released from its hopper, and an electric motor-driven rotary cylinder, fins on which moved granules until they dropped into a 3-in (7.6-cm) diameter, 8-ft (2.4-m) long tube. Granules were moved through the tube by an airstream of approximately 60 mi/h (96 km/h) provided by a hydraulically powered blower.

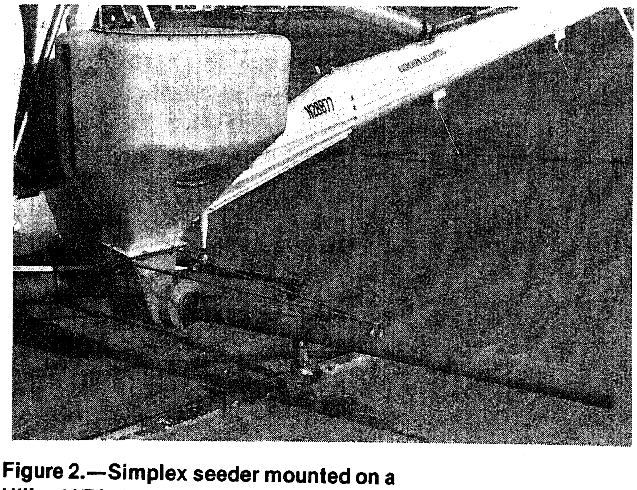


Figure 2.—Simplex seeder mounted on a Hiller 12E helicopter was used in early tests but the granules jammed the feeder mechanism.

The seeder proved to be unsatisfactory. The incredibly tough polyamide dimer acid granules lodged between the rotor fins and the housing, jamming the feed mechanism, overloading the motor circuit, and causing mechanical problems such as slippage of a drive wheel and piling of granules in the air tube and consequent uneven flow rate. The seeder was tested on six flights prescribed at 45 mi/h (72.4 km/h) and 50-ft (15.2-m) elevation. The overall swath width varied from 80 ft (24.4 m) to 100 ft (30.5 m), probably due to inadvertent differences in aircraft height and variable low -velocity lateral wind.

SIMPLEX MODEL 3700 APPLICATOR

After consultation with representatives of Simplex Corporation, Portland, Oreg., we selected a model 3700, bucket-type applicator (fig. 3) for modification and testing. The applicator was designed for applying fertilizer pellets at high rates, up to 200 lb/acre (224 kg/ha). It consisted of a 40-ft^3 (1.13-m^3) fiberglass bucket with an internal mechanism (fig. 4) for metering outflow of granules and an externally mounted 10 hp gasoline motor that drove a horizontal spinning disc at the bottom of the bucket to disperse granules. The internal mechanism consisted of a central column (can) on top of which was a reversing electric motor that turned a screw shaft to open or close an internal, cylinder-shaped gate at the bottom of the can. The continuous opening created when the cylinder gate was raised is satisfactory for high rates of fertilizer application but not for the low rate required for formulated MCH.

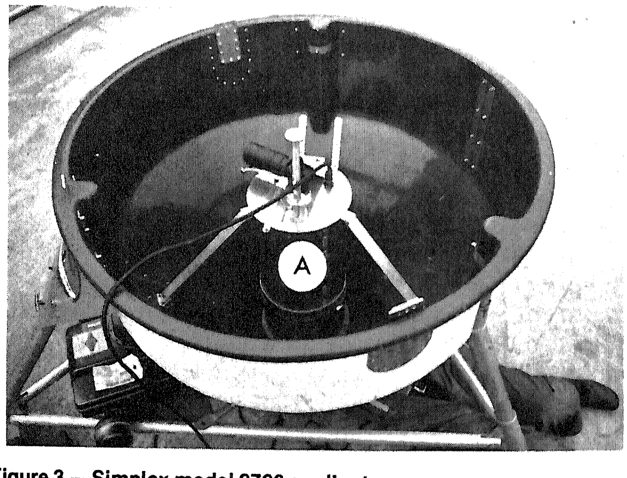


Figure 3.—Simplex model 3700 applicator had a weakly supported internal mechanism (A) that resulted in misalinement and jamming of the gate mechanism by granules.

[1]Simplex Manufacturing Co., 5224 NE 42d Avenue, Portland, OR 97218.

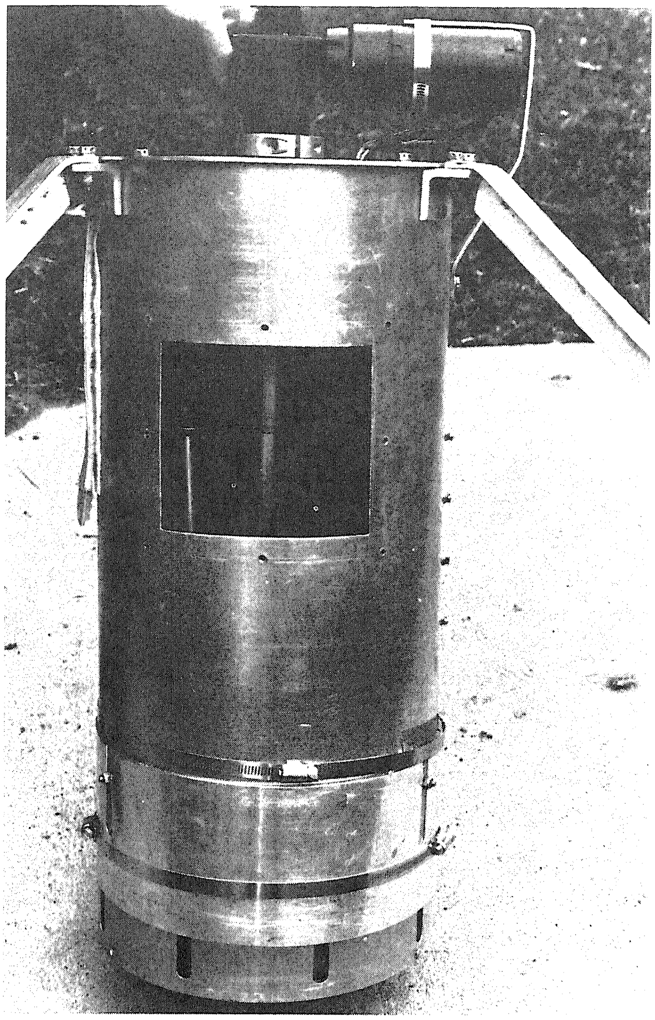


Figure 4.—Internal mechanism removed from model 3700 applicator to show slotted band and sliding collar at bottom.

The applicator was modified to reduce output of granules by installing a slotted aluminum band inside an adjustable aluminum collar (fig. 4). Eight vertical slots, 0.5 in (1.27 cm) by 4 in (10.2 cm), were cut equal distances apart in the aluminum band. The collar was positioned to provide a desired slot opening and then held fast to the slotted band by a hose clamp.

The modified model 3700 applicator was calibrated on the ground to deliver approximately 18 lb/min (8.2 kg/min) of granules with the collar set for a slot opening of 0.4 in (1 cm). That rate was calculated to provide 4 lb/acre (4.48 kg/ha) based on a 50-ft (15.2-m) working swath, at 45 mi/h (72.4 km/h) and 50-ft (15.2-m) height.

The applicator was flown on a Hiller 12E helicopter over conical traps set at 10-ft (3-m) intervals across the direction of flight (described later under evaluation) at 45 mi/h (72.4 km/h) and 50-ft (15.2-m) elevation to determine swath width and uniformity of application. Eight swaths averaged 106 ft (32.3 m) wide (R = 80 – 120 ft, 24.4 – 36.6 m). Because of the bell-shaped distribution of granules of a single application, a working swath width of 50 ft (15.2 m) was selected to provide overlap needed to obtain the desired average application rate (see Akesson and Yates 1974). When the granules from eight swaths were plotted with the flight lines 50 ft (15.2 m) apart, the average rate of application was 4.6 lb/acre (5.2 kg/ha) ± 20 percent. This rate was 15 percent higher than the recommended rate but could be adjusted either by increasing the aircraft speed, or reducing the slot openings.

In April 1979 the Simplex model 3700 applicator was used to apply granules containing MCH to forested plots on which trees were felled to simulate windthrow (Furniss and others 1981). Several problems developed with the applicator, as discussed subsequently, that contributed to varying rates of application. Even so, treatment rates averaging 1.58 to 10.98 lb/acre (1.41 to 9.80 kg/ha), measured on plots, reduced DFB attack density from 92 to 97 percent, indicating that an average rate of approximately 4 lb/acre (4.48 kg/ha) would be satisfactory.

The problems with the applicator were: (1) slot openings were difficult to set and required emptying the bucket and climbing inside, (2) catching and weighing granules during calibration of the applicator was inconvenient, (3) gate position could not be positively determined while in flight, (4) various internal mechanical and electrical problems occurred. Solutions to those problems were found by adapting an improved applicator (model 6400) as explained in the following section.

MODIFICATION OF SIMPLEX 6400 APPLICATOR

The model 6400 applicator differed from the earlier 3700 model by having better support (fig. 5, 6) for the can that housed the gate mechanism. The supports stabilized the can, preventing misalignment of the gate that occurred with the model 3700 and avoided binding of the gate's movement by the nearly indestructible granules that lodged wherever misalignment caused a gap. We still found it necessary to modify some components, however, as discussed hereafter.

Due to the three vertical braces along the outer surface of the can, a single slotted-aluminum band could not be fitted around the can to restrict output. Instead, we installed three discontinuous stationary bands (fig. 5), each having three slots measuring 0.44 in (1.11 cm) wide by 4 in (10 cm) long. Outside each slotted band, we fitted a concentric sliding plate attached to a threaded, vertical, 0.25-in (6.4-mm) diameter control rod with an inscribed reference scale opposite its top end (fig. 6). The control rods enabled setting each plate for a precise slot opening without emptying or entering the bucket. Two lock nuts kept each plate from moving, once adjusted. Each plate and its slotted band were custom fitted to prevent gaps where granules might lodge.

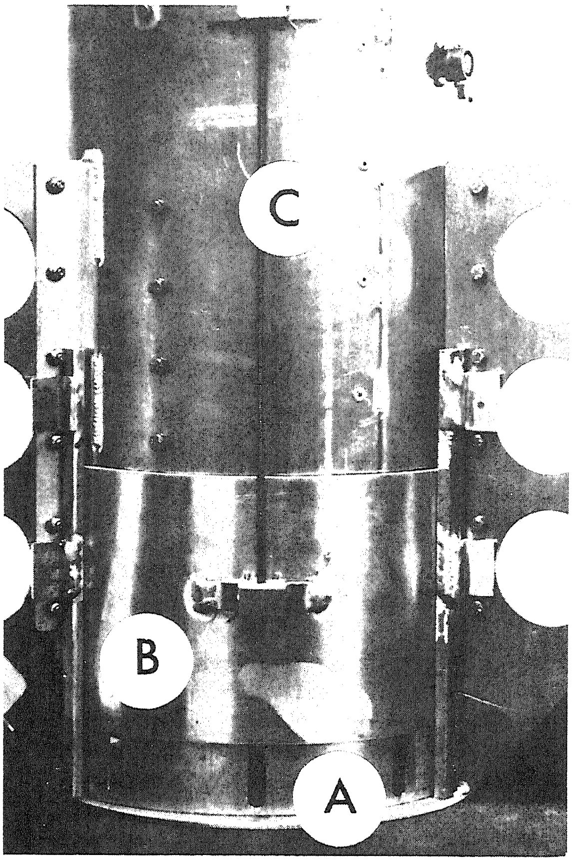


Figure 5.—Internal mechanism of model 6400 applicator showing slotted band (A) and sliding gate (B) installed between perforated side supports. The gate is raised and lowered by a threaded rod (C).

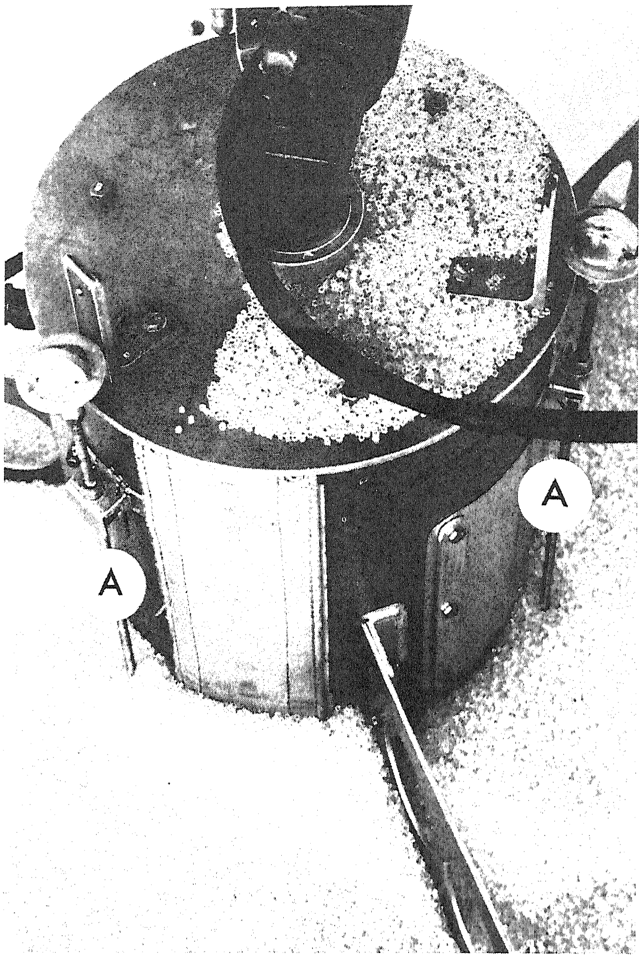


Figure 6.—Details of top of internal mechanism of model 6400 applicator loaded with granules. The opening of each gate can be conveniently and accurately regulated by turning the threaded control rods (A).

To conveniently catch granules during preflight ibration of slot openings, we built and installed a .cher (fig. 7) of 24-gage galvanized sheet iron, with a ump spout at the bottom. The catcher was installed by raising the applicator on blocks. Because the spinning disc caused granules to bounce and escape through the narrow top opening, we installed a spiral cleat inside the catcher to deflect granules downward. Also, the opening at the top of the catcher was reduced to a minimum with nylon netting and Velcro fasteners. With the catcher in place, we ran 30-second replicates at intervals of about 1 minute.

A red light was attached to an external support on the applicator to signal to observers on the ground when the gate was open. The light was a single-contact automotive-type directional light having an Auto Lamp No. 567 bulb (24 v, 32 candlepower). The light was activated by a microswitch mounted inside the bottom of the can.

We found it desirable to install a positive up (on) and positive down (off) toggle switch on the pilot's control stick to indicate that the gate was open or closed. A spring-loaded switch would require the pilot to maintain the switch in the on or off position until the gate had closed or opened. The pilot cannot monitor the gate position, however, and other duties while flying make it desirable to free the pilot by using a positive on or off switch.

The housing of the switch that we built was sufficiently large that its weight changed handling characteristics of the control stick. Thus, care should be taken to keep its weight minimal and to have the pilot flight test it before the applicator is attached. A fuse should be incorporated into the switch housing for safety.

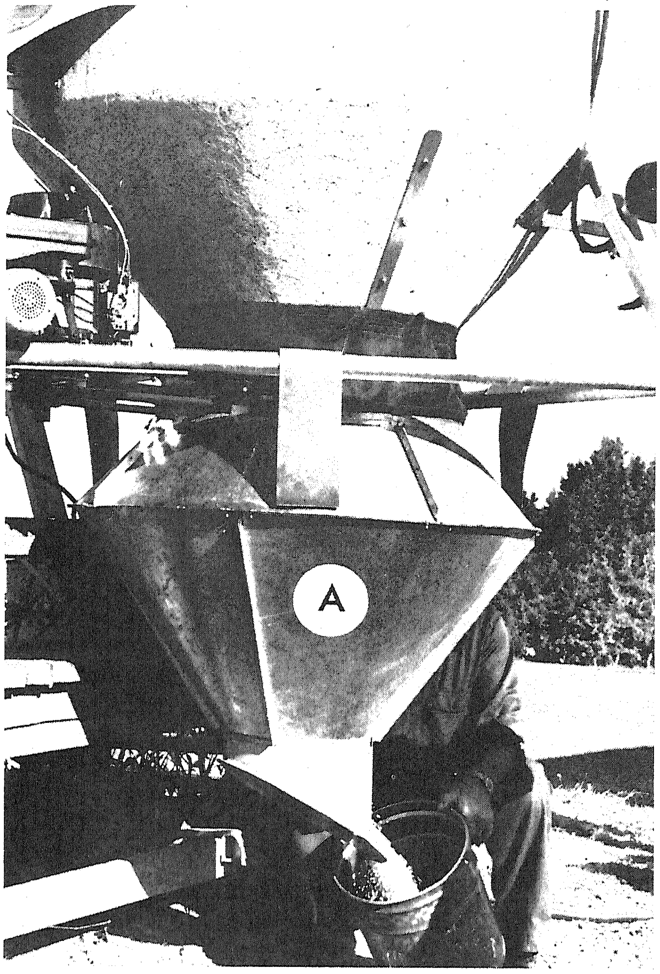


Figure 7.—Catcher (A) installed beneath applicator to catch granules during static calibration tests.

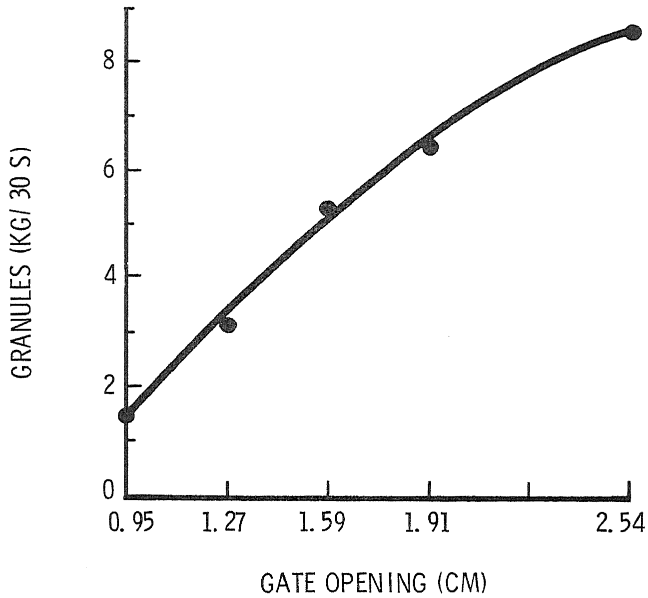
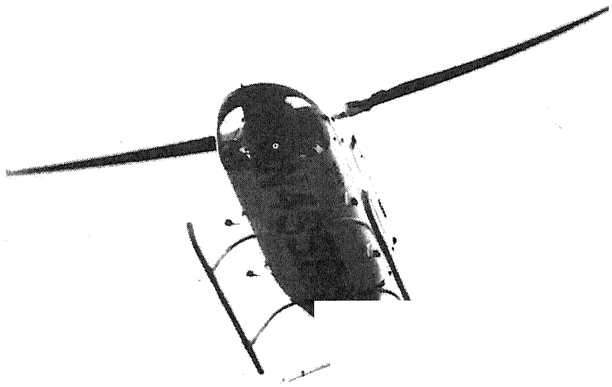


Figure 8.—Relationship between slot opening and output of granules.



CALIBRATION OF THE MODIFIED MODEL 6400 APPLICATOR

With the applicator on blocks and the catcher in place, we ran 30-second replicates to determine relationship of slot openings and output of granules. A slot opening of 0.63-in (1.6-cm) height (2.5 in^2 [16 cm^2] total for the nine slots) resulted in an average output of 11.7 lb (5.32 kg)/30 s ($n = 54$, SD = 0.71 lb = 0.32 kg). Using the relationship shown in figure 8, other slot openings can be selected for other application rates.

After calibration, we flight-tested the modified applicator (fig. 9) with 0.63-in (1.6-cm) slot openings to determine rate of application of two overlapping swaths 50 ft (15.2 m) apart. The applicator was tested with a Bell 206 helicopter on September 10, 1980, at 2,950-ft (900-m) elevation in Smith Meadow 3 mi (5 km) north of Deary, Idaho. Eleven conical traps (described under Evaluation of Treatment) were set out 10 ft (3 m) apart on five lines at right angles to the direction of flight. Lines were 200 ft (61 m) apart. The pilot was requested to fly at 50 mi/h (80 km/h) with the bucket 50 ft (15.2 m) above ground. Sixty flights,

in pairs of two flights 50 ft (15.2 m) apart, were made. The applicator functioned without any problem and the indicator light allowed us to immediately detect one flight on which the pilot failed to turn on the switch. Results are shown in table 1.[2]

Table 1.—Application rates at 200-ft intervals for overlapping swaths 50 ft apart

Interval	Number of traps observed	Lb/acre	(kg/ha)	Coefficient of variation
1	180	3.29	(3.69)	63
2	180	3.75	(4.20)	51
3	180	4.12	(4.62)	50
4	180	4.18	(4.69)	51
5	180	4.31	(4.83)	53
Average		3.93	(4.40)	55

The variation within lines is mainly due to the ballistics of nonuniform size granules. Similar variation did not lessen the effectiveness of MCH odor in a recent test (Furniss and others 1981). We did, however, look for other sources of variation in application rate between lines.

We monitored the speed of the helicopter with a stopwatch and found that it traversed 1,090 ft (332 m) in an average of 15.4 s (R = 13.5 to 17.8), which was equal to 48 mi/h (77.7 km/h) (R = 43 to 55 mi/h [67 to 88.5 km/h]). Thus, some of the variation was attributed to deviation from the specified aircraft speed.

We also measured the height of the bucket above ground at lines 1 and 5. The average height at line 1 was 63 ft (19.2 m); at line 5 it was 52 ft (15.9 m). The probable reason for the higher height at line 1 was the presence of a forested hill that may have caused the pilot to approach higher from that end. The probable effect of higher elevation would be less dense dispersal of the granules, which is indicated in table 1.

EVALUATION OF TREATMENT

Rate of application should be determined by sampling granules that fall on the ground. A suitable way of doing so is with a funnel trap (fig. 10) modified from that described by Stringer and others (1973).

The trap has a 3-ft^2 (0.28-m^2) (23.5-in, 59.7-cm diameter) top opening and a 0.63-in (1.6-cm) diameter bottom opening. The funnel is 20 in (0.51 m) deep and is made of a 24-gage galvanized sheet iron with a spotwelded seam. A flaring tool is used to form a uniform bottom opening and to reshape holes that become deformed during transportation to the field. A 2-in (5.1-cm) length of 3/4-in (2-cm) inside diameter PVC tube with a window screen bottom for draining rainwater is attached to the funnel outlet with a wire clip to collect granules (fig. 10B). A stand made of 1/4-in (0.64-cm) diameter iron is thrust in the ground to hold the funnel upright. Tape can be applied to assure that the funnel is held upright in the stand.

For operational use it may be more practical to count, rather than weigh, granules caught by traps. The equivalent rate of application in pounds per acre (kilograms per hectare) of the number of granules caught per 3-ft^2 (0.28-m^2) cone trap can be calculated by multiplying the number of granules caught per trap times a conversion factor. Based on an average weight of 12.90 mg per granule in our 1980 calibration test, the factors were 0.41294 (= lb/acre) and 0.4623 (= kg/ha). New factors may be derived by the proportion of any different average weight per granule (X) times our factor; e.g., (X/12.90) (0.41294).

An alternative method is to remove the tubes containing granules, apply a cork stopper, and place them in a carrying case for eventual weighing. The weight of granules (in grams) per trap can be converted to pounds per acre by multiplying by 32.01 or to kilograms per hectare by multiplying by 35.88.

Cones should be placed across flight lines but clustered in the vicinity of windthrow, which may be unevenly distributed. Sampling in the vicinity of windthrow will take advantage of more open overstory, and the density of application there may be more important in reducing subsequent DFB infestation.

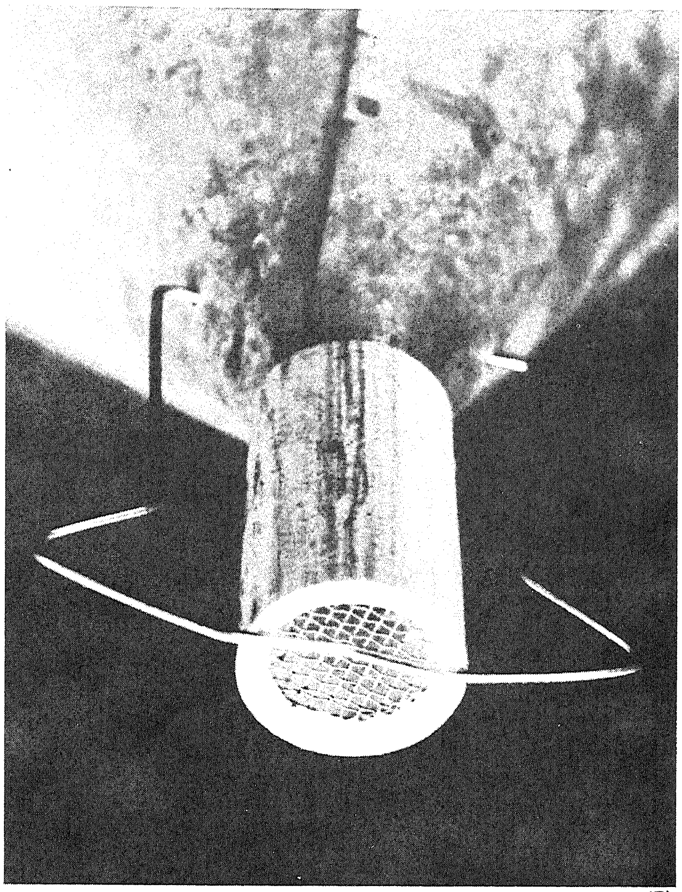
The number of cone traps set out will be limited by their bulk, work force available, and cost. We used 7.43 traps per hectare for study purposes (Furniss and others 1981).

Bioassay of Treatment

DFB infestation in windthrown trees can be evaluated by (1) counting piles of "frass" (mostly expelled phloem fragments) on bark, (2) counting and measuring egg galleries on bark samples, and (3) counting progeny on bark samples. The three methods are listed in increasing order of work and time involved.

[2]Based on granules caught by traps between the flight lines, in order to obtain overlap of two flights.

(A)



(B)

Figure 10.—(A) Conical trap used to catch granules during aerial test of applicator. (B) Detail of removable screen-bottom tube installed at outlet of trap.

FRASS COUNTS

Frass is conspicuous in early June while it is bright orange and has not been bleached by sun or diminished by rain or wind. Although attacks may be hidden from view on the underside, counts of visible frass can provide a preliminary evaluation of treatment and indicate whether or not bark samples may be needed. A decision on whether to proceed with obtaining bark sample data is influenced by cost, which was 50 times greater than for counting frass in a recent test (Furniss and others 1981). If bark sampling is deemed necessary, it can be expedited by stratifying trees by densities of their frass counts in order to weight the samples to represent the population. Those trees having few or no visible attacks need not be sampled.

BARK SAMPLES

Factors that influence the location of sampling for DFB are: DFB attacks in felled trees are usually more dense on the underside (Furniss 1962), especially if the upper side is sun-exposed, and a less important bark beetle, *Pseudohylesinus nebulosus* Lec., may predominate in portions of the trunk smaller than 12 in (30 cm) in diameter.

For statistical efficiency, the area of the ultimate sampling unit should vary inversely with density of the variable sampled. Because DFB egg galleries (or attacking parent beetles) are less dense in windthrow than the number of progeny produced, we commonly use a 12- by 12-in (30- by 30-cm) sample (fig. 11) for measuring attack density and a subsample of 6 by 6 in (15 by 15 cm) for progeny.

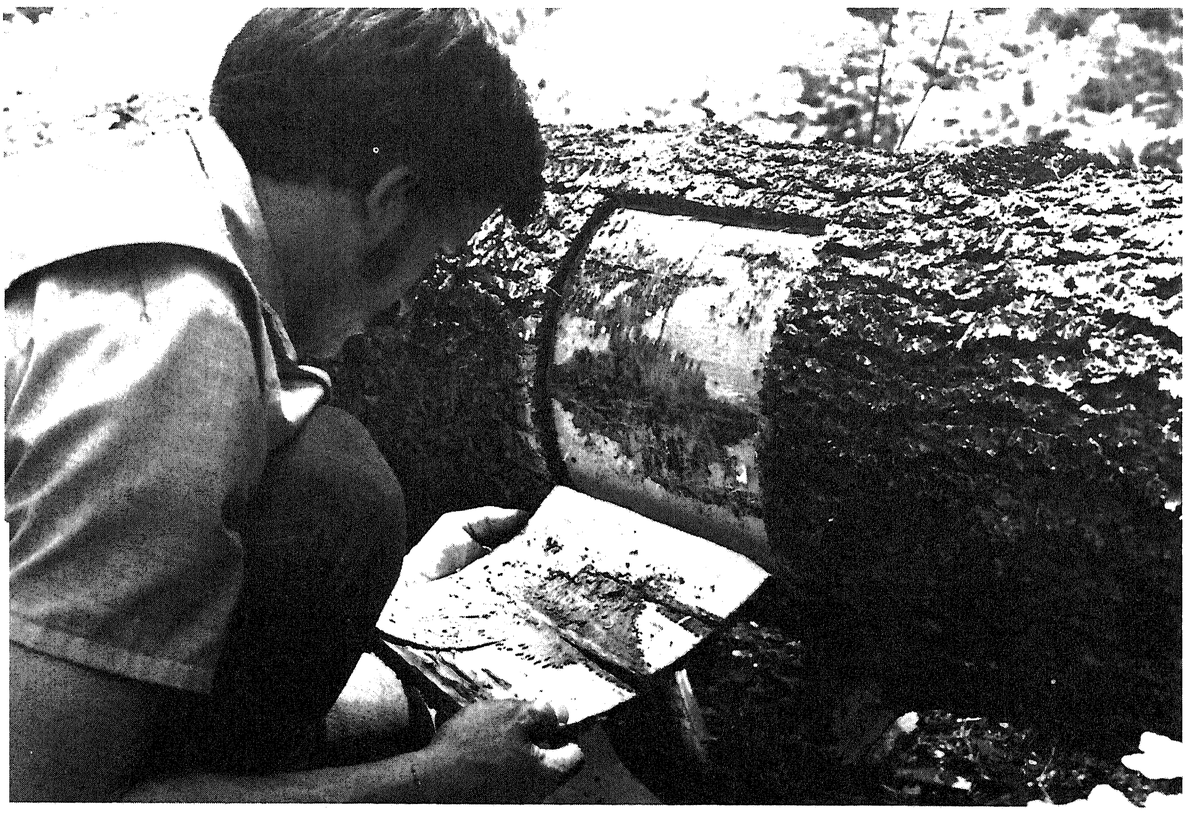
A practical procedure is to take three bark samples on the lower, shaded side, spaced equidistant below a 12-in (30-cm) diameter, for example one-fourth, one-half, and three-fourths of the distance between the root crown and the 12-in (30-cm) diameter. The number of such samples required for estimating the mean density of attack or progeny varies with the level of probability and accuracy desired and with the particular trees and population level. A good method is to sample several representative trees and solve for the needed number by the formula: $n = (CV_x/0.20)^2$ as suggested by Kish (1965). Of course, other relative coefficients of variation of the mean can be substituted for 0.20 in the formula.

EVALUATION OF TREE MORTALITY

Measurement of the reduction of tree mortality due to treatment of windthrow with MCH is difficult. The sources of beetles that infest live trees can only be inferred. The beetle is a good flyer, having been observed to fly continuously up to 6 h at an average of 2.5 mi/h (4 km/h) on flight mills like those described by Smith and Furniss (1966). More than one flight may occur. But many beetles probably respond to environmental stimuli, including odors of trees being infested, if present, within a few miles of flight. Once a female beetle arrests her flight and begins invading a tree, a powerful attraction is created by the interaction of her aggregating pheromones, frontalin and seudenol (Pitman and Vité 1970; Pitman and others 1974) and resin odor (Furniss and Schmitz 1971). The ensuing aggregation of beetles typically results in a discrete group of trees being infested. Such trees become discolored and appear red by June of the following year, and can be readily detected on aerial photos taken then (McGregor and others 1975).

Evaluation of tree mortality in stands surrounding MCH treatment should begin by taking aerial photos during July of the year of treatment to obtain a base for comparison with later measurements. DFB progeny will not emerge until the year following MCH application. Trees that they infest will not have entirely discolored until a year later. Thus, final evaluation of tree mortality after MCH treatment is not possible until 2 years after treatment.

Groups of discolored trees killed by DFB are easily identified on true color stereo aerial photos of 1:15840 scale or larger. We recommend obtaining such aerial photos of stands in a 3-mi (4.8-km) radius around the MCH-treated area containing windthrow. With such photos, crews can readily locate and measure groups of DFB-killed trees. Should the mortality be so extensive as to require it, discolored trees can be counted on the photos and those counts adjusted by measuring sample groups on the ground (McGregor and others 1975).



:igure 11.—Bark sample used to measure)ouglas-fir beetle infestation in windthrown rees.

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